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Monthly Report

PAR 211

29 Oct 65

SUBJECT: Microdensitometer Study of Effects of Processing

TASK/PROBLEM

1. Collect and study microdensitometric data from mission materials in an attempt to determine the effect of film emulsions, processing, and printing on the characteristics of image edges. Also, attempt to determine the true location of image edges for mensuration purposes.

DISCUSSION

2. The final report, PAR 211, Microdensitometer Study of Effects of Processing, (AL-45-700092-), dated 20 August 1965, was transmitted to the customer on 28 October 1965.

PLANNED ACTIVITY

3. Publication of the final report constitutes project termination.

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Approved For Release 2005/05/02 : CIA-RDP78B04770A002400020013-1

SUMMARY

Image structure data have been collected on three typical aerial negative film types: 4400, 4401, 4404. Seven processings were used for these materials. These were the standard Trenton three-condition processes and four sensitometric processings: two with special purpose developers designed to give high sharpness and two with special purpose developers expected to give low graininess.

It was found that the Trenton processing produced higher acutance and better low contrast resolving power than did any of the special formulations for the 4400 and 4404 films. The special formulations showed lower granularity than the Trenton processing for all three emulsions. The state-of-the-art appears to be that optimum sharpness and optimum granularity are mutually exclusive, and that a practical mission developer should be selected as a best compromise of sharpness and granularity in combination with some other properties such as increased emulsion speed or exposure control through processing.

Comparative evaluations using simulated photography, printing tests, and complete modulation transfer measurements were planned, but could not be scheduled before project termination. Study was made of the customer's mensuration problem, and recommendations for further work are included in this report.

20 Aug 65

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INTRODUCTION

2. An ideal photoreconnaissance system should, among other things, completely resolve all ground detail and permit accurate determination of the size of all ground objects. That photographic systems always depart from this ideal is well known. It was the intention of this project to study the relationship of some of the distortions or non-linearities of the photographic system with changes in developer composition. It was hoped that a knowledge of the causes of these distortions might point the way toward methods for reducing the degradations or might alternatively indicate ways to compensate for the degradations.

3. It was proposed that several high quality negative films would be processed with standard and special purpose developers, and then be evaluated for acutance, granularity, resolving power, and modulation transfer function. Prints of simulated aerial scenes would be made from these negative/processing combinations permitting subjective evaluation for comparison with the objective measurements. As a separate part of the project, it was proposed that a visit be made to the customer's shop to see his methods of linear mensuration, to form a background for studies in methods of improving mensuration at or near the limit of resolution.

4. Termination of the work phase of this project has made it impossible to realize all of the proposed goals.

DISCUSSION

5. Film Selection: The proposal called for the use of three photographic films in this project. These were:

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a. [redacted] Panatomic-X Aerial Film (Estar Thin Base), Type 4400.*

b. [redacted] Plus-X Aerial Film (Estar Thin Base), Type 4401.*

c. [redacted] High Definition Aerial Film (Estar Thin Base), Type 4404.*

These films are in common usage in aerial reconnaissance at low to very high altitudes and are representative of the current state-of-the-art in medium to slow speed films (exposure index of 64 to 1.6). The inclusion of other film types was not believed necessary at the start of the project. That assumption appears to be correct. Any further work along the lines of this study should continue investigation of the image structure of these films, rather than add more film types to the investigation.

6. Processing: Of the almost unlimited number of developer formulations available, the choice for investigation was restricted to two standard spray formulations as used in Trenton Primary, Trenton Intermediate, and Trenton Full processing, and four special purpose formulations: two producing

* These films are now identified as Types 3400, 3401, and 3404. The 3000 designation identifies the base and base thickness.

high sharpness and two yielding low graininess. The latter four were selected from the nine studied by Altman and Henn (see Attachment 1), in which a systematic study was made of the relationship of image structure characteristics with variation in the silver solvent concentration (leading to reduced graininess) and variation in the developing agent concentration (leading to increased sharpness).

a. Trenton Process

(1) Processing conditions for these three films in the Trenton spray processor were established prior to the start of this project. This processing was known to give processing contrasts (gammas) of approximately 2.0, emulsion speeds faster than the normal ratings for these films, and good control of the emulsion speed to compensate for exposure deficiencies. The image quality of these films processed by Trenton three-condition methods was believed to be good, but the comparison with special purpose formulations was not known.

(2) Table 1 shows the developers, times, and the temperatures used in Trenton processing. Also included is the processing contrast (gamma) and the aerial speed index* calculated for each film/processing combination.

* Aerial Speed Index = $\frac{1}{2 \times E}$

where E is the exposure in meter-candle-seconds at a point in the toe region of the negative film curve relating density to log of exposure (H & D curve), at which the slope is 0.6 of the straight line portion (gamma).

Table 1

DEVELOPMENT CONDITIONS FOR TRENTON PROCESS

		First Developer*			Second Developer*				Aerial Speed
Film	Condition	Type	Time	Temp. °F	Type	Time	Temp. °F	Gamma	Index (at 0.6 Gamma)
4400	Primary	D-19	1'55"	70	- - -	- - -	- - -	1.84	9.6
	Intermediate	D-19	1'55"	70	MX-579	28"	80	2.18	13.2
	Full	D-19	1'55"	70	MX-579	1'38"	80	2.26	18.2
4401	Primary	MX-576	2'	70	- - -	- - -	- - -	1.77	39.0
	Intermediate	MX-576	2'	70	MX-579	20"	80	2.24	42.5
	Full	MX-576	2'	70	MX-579	2'12"	80	2.26	55.0
4404	Primary	MX-574	2'15"	74	MX-577	- - -	- - -	1.98	1.82
	Intermediate	MX-574	2'15"	74	MX-577	25"	67	2.18	2.29
	Full	MX-574	2'15"	74	MX-577	1'16"	67	2.02	3.46

* Formulas for Developers are proprietary except for D-19, which is given below for a 1 liter mix:

Chemical	Amount
Water	300 milliliters
Calgon	0.5 grams
Elon	2.0 grams
Sodium Sulfite	90.0 grams
Hydroquinone	8.0 grams
Sodium Carbonate (anhydrous)	43.9 grams
Potassium Bromide	5.0 grams

Water to 1 Liter

b. Special Processing

(1) All of the developer formulas given in the Altman and Henn article (Attachment 1) were tried in a preliminary screening. Of the eight possible formulations, two, AH-3 and AH-4 were selected to represent special purpose, fine grain developers, and two, AH-15 and AH-18 were picked for the high sharpness comparisons. All special processing of the 4400, 4401, and 4404 films for image structure testing was conducted in the Kodak Small Capacity Sensitometric Processor (see Figure 1). The preliminary screening showed that it would not be possible to obtain the gamma of 2.0 achieved in the Trenton process with these formulations. It was therefore decided to adjust the agitation rate, times, and temperature to levels that would give a gamma of 0.85 ± 0.10. While processing was consistent from batch to batch, it was not possible to stay within the tolerance. Adjustment of the chemical formulas was a possibility but this approach was discarded in favor of staying with published formulations. It is believed that the first order affects of gamma change on image structure characteristics are small; and that adjustments could be made in the tone reproduction of the aerial simulations to compensate for the variation in the gammas of the special purpose developer series.

(2) The resultant gammas and emulsion speeds produced in the special processing series are given in Table 2.

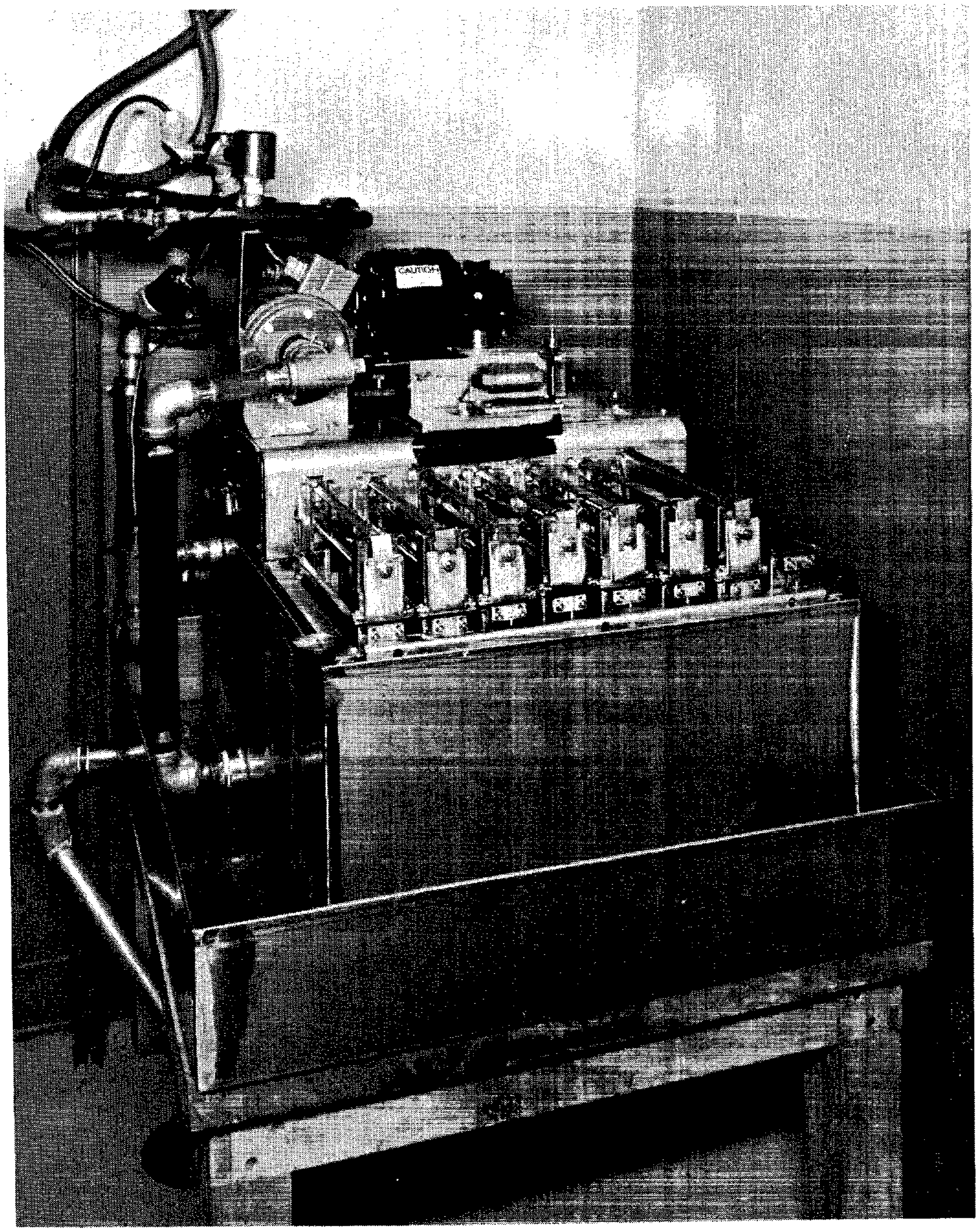

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Figure 1. Small Capacity Sensitometric Processing Machine

Table 2

DEVELOPMENT CONDITIONS FOR SENSITOMETRIC PROCESS

Film	Developer*	Time (Min.)	Temperature (°F)	Gamma	Aerial Speed Index (at 0.6 Gamma)
4400	AH-3	8	68	0.81	9.6
	AH-4	11	68	0.87	14.8
	AH-15	2	68	0.93	5.9
	AH-18	10	68	0.77	27.5
4401	AH-3	12	68	0.88	47.9
	AH-4	14	68	0.85	47.9
	AH-15	2.5	68	0.78	25.0
	AH-18	14	68	0.78	79.5
4404	AH-3	4	68	0.73	0.77
	AH-4	5	68	0.78	1.02
	AH-15	1	68	0.78	0.81
	AH-18	4	68	0.76	1.94

* Developer formulas are given in Attachment 1.

7. Measurements

a. Acutance

(1) Of the image structure parameters studied in this project, the one of primary interest was that of image edge quality. The fundamental importance of edges comes from their dual role in determining the subjective impression of sharpness (i.e.: definition) and in their role as the boundaries for linear mensuration. Among image quality measurements, edge evaluation appears to be the least precise and probably the least accurate. Two edge evaluation techniques are currently in use: acutance, and modulation transfer function derived from edges. Only the former method was used in this film/processing study for it is the simpler method and has been in use a longer time. Both methods are controversial at the present time.

(2) Acutance was proposed by Higgins and co-workers (see Reference 1) as an objective measurement having correlation with the subjective sensation of sharpness in a photograph. It is a laboratory measurement that has substantially reduced the necessity for extensive psychometric testing of new photographic products. The procedure is to expose a film in intimate contact with an opaque, sharp knife edge. After processing, the resultant image is traced on a microdensitometer. The microdensitometric data are reduced by hand or computer methods to yield acutance values as a function of the incident exposure. The maximum value for this curve is given as the single acutance number for the film/processing combination under test.

(3) In undertaking this project, it was necessary to provide a large number of acutance exposures. An exposing device* was built (see Figures 2, 3, and 4) consisting of a knife edge, light source, line voltage regulator, and timer mounted in a light-proof box. The knife edge is a sharp edge exposed on a high resolution photographic plate. In the light path ahead of the knife edge is a carbon step tablet used to modulate the exposure along the edge. The light source is a small tungsten filament lamp and the light path is folded by means of a front-surface mirror so that the exposing light is reasonably specular. The film under test is held by vacuum contact during exposure.

25X1 (4) A [redacted] Model 5 microdensitometer was used to scan the samples. This instrument (see Figures 5 and 6) is provided with both strip chart recorder and direct card punching capability. This latter facility, and ready access to I.B.M. 1620 and 7044 digital computers, permitted the reduction of large volumes of acutance data. The FORTRAN program, written for the acutance computations, is given in Appendix 1.

(5) While acutance measurements have shown correlation with subjective definition, it has not been shown that acutance and capability for linear mensuration are correlated, although this would intuitively seem to be the case.

(6) Acutance values found for the different film/processing combinations are compared in Figures 7, 8, and 9.

* This equipment represents the only item fabricated under PAR 211. Other instruments and hardware mentioned in this report were procured or built under other programs.

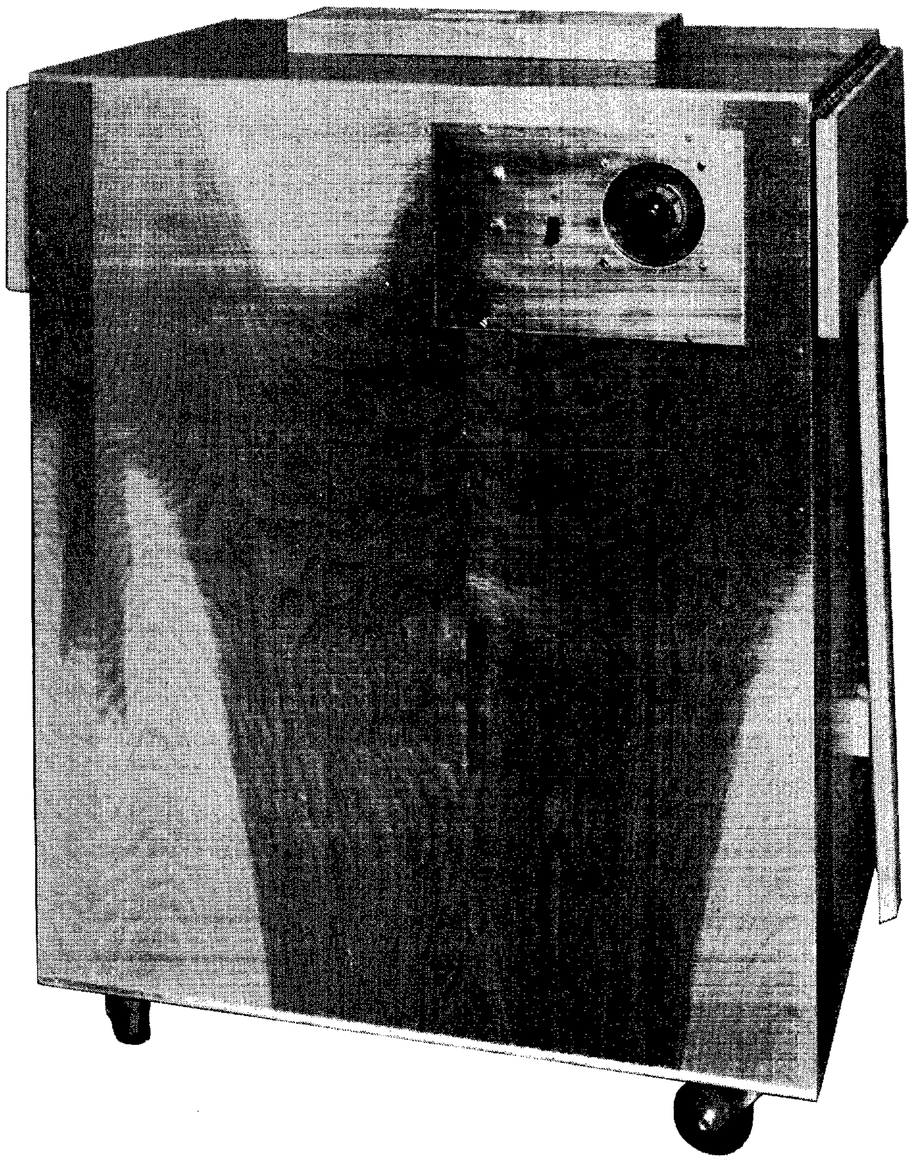

Figure 2. Acutance Exposure Printer:
Knife Edge Plane at Top (Covered)

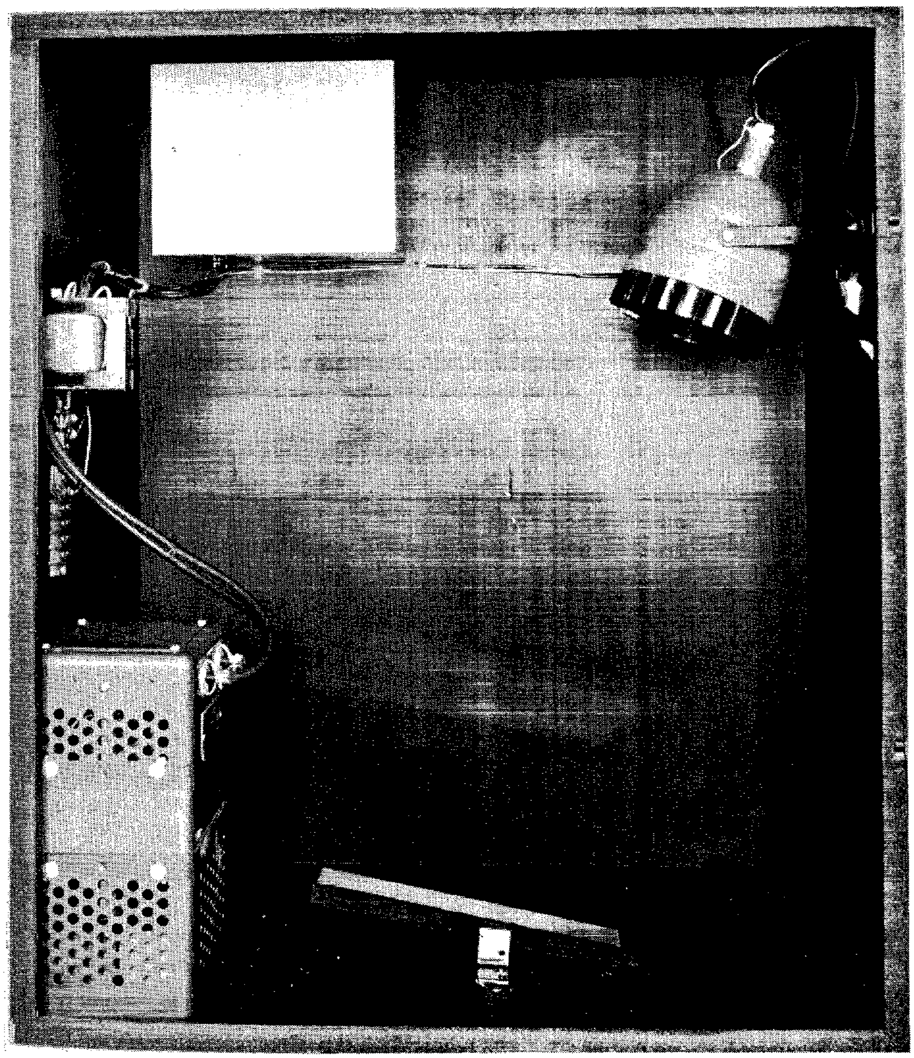

Figure 3. Interior of Acutance Printer: Power Supply, Lamp and Inclined Mirror

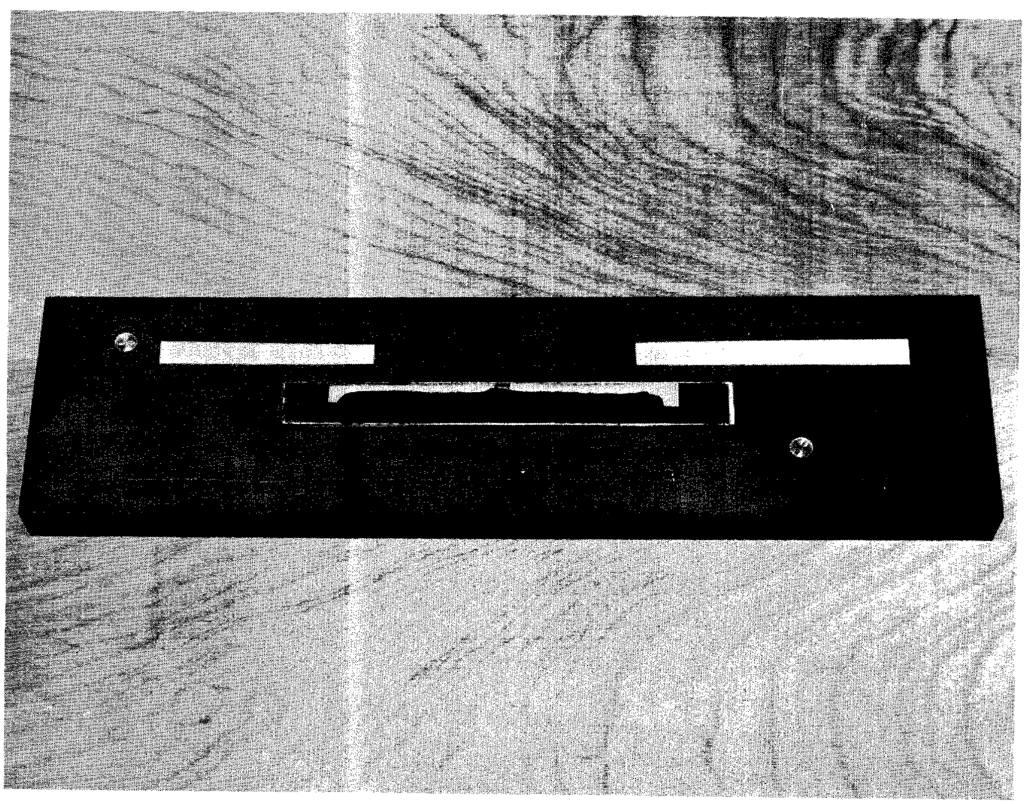

Figure 4. Top of Acutance Printer: Knife Edge with Step Tablet

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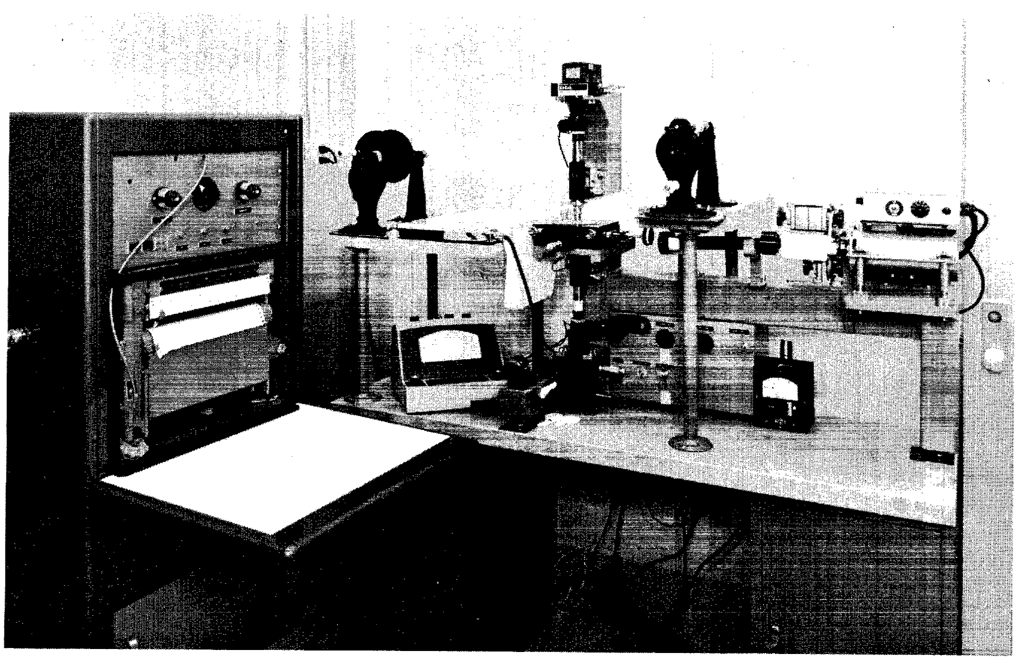

Figure 5. Model 5 Microdensitometer: Optical and Recording Apparatus

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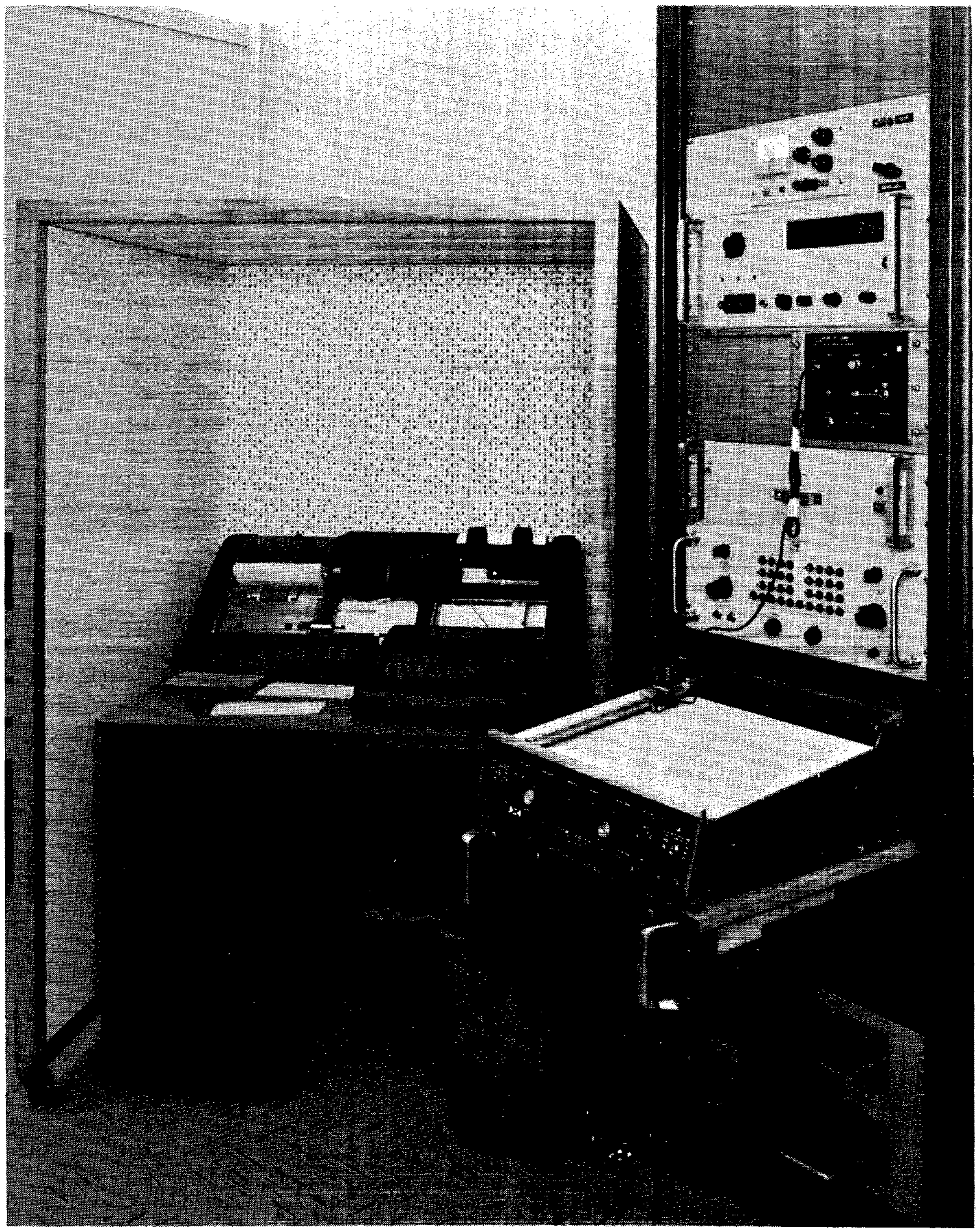

Figure 6. Model 5 Microdensitometer:
Data Converter and Card Punch

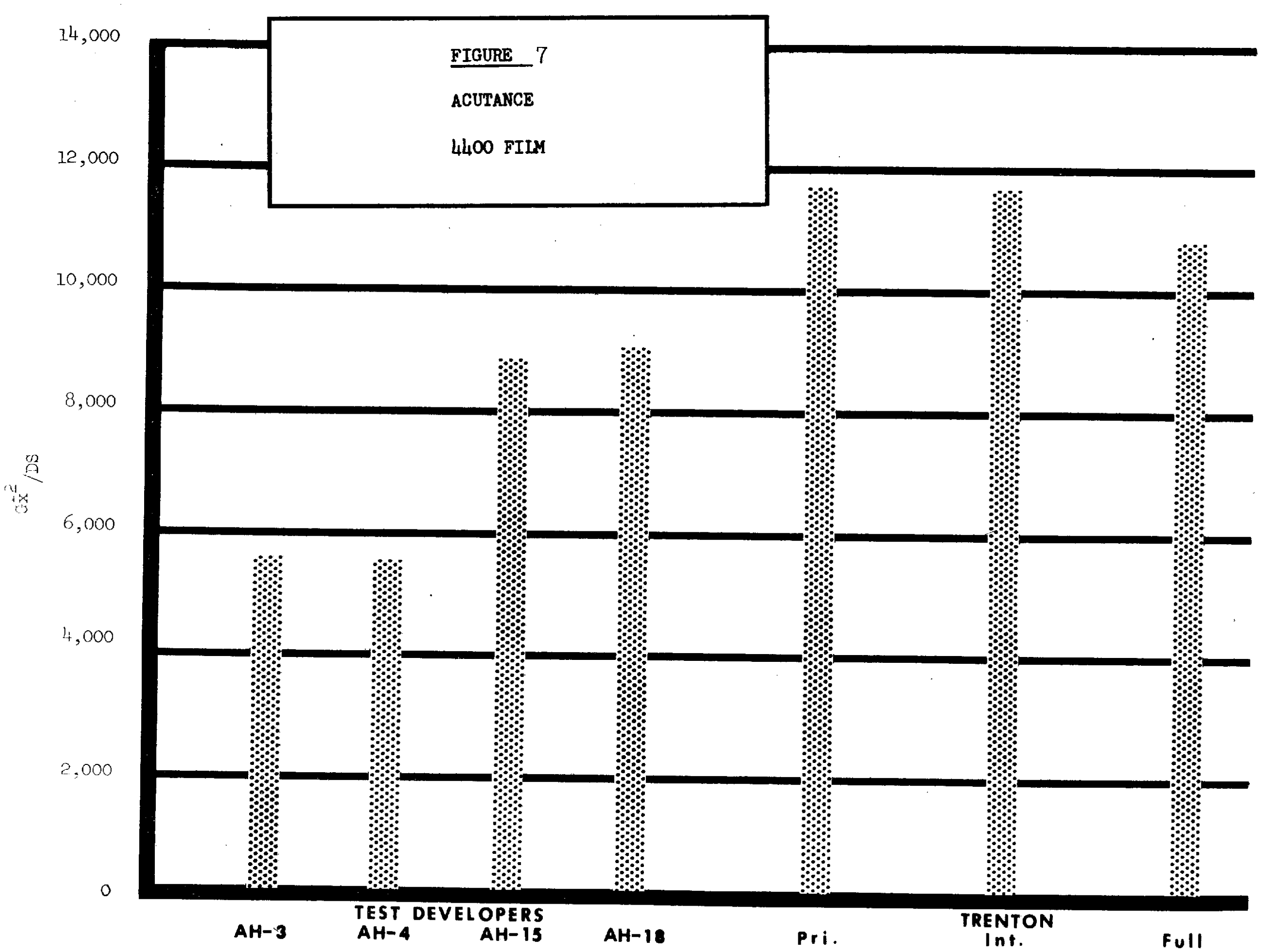

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FIGURE 8

ACUTANCE

4401 FILM

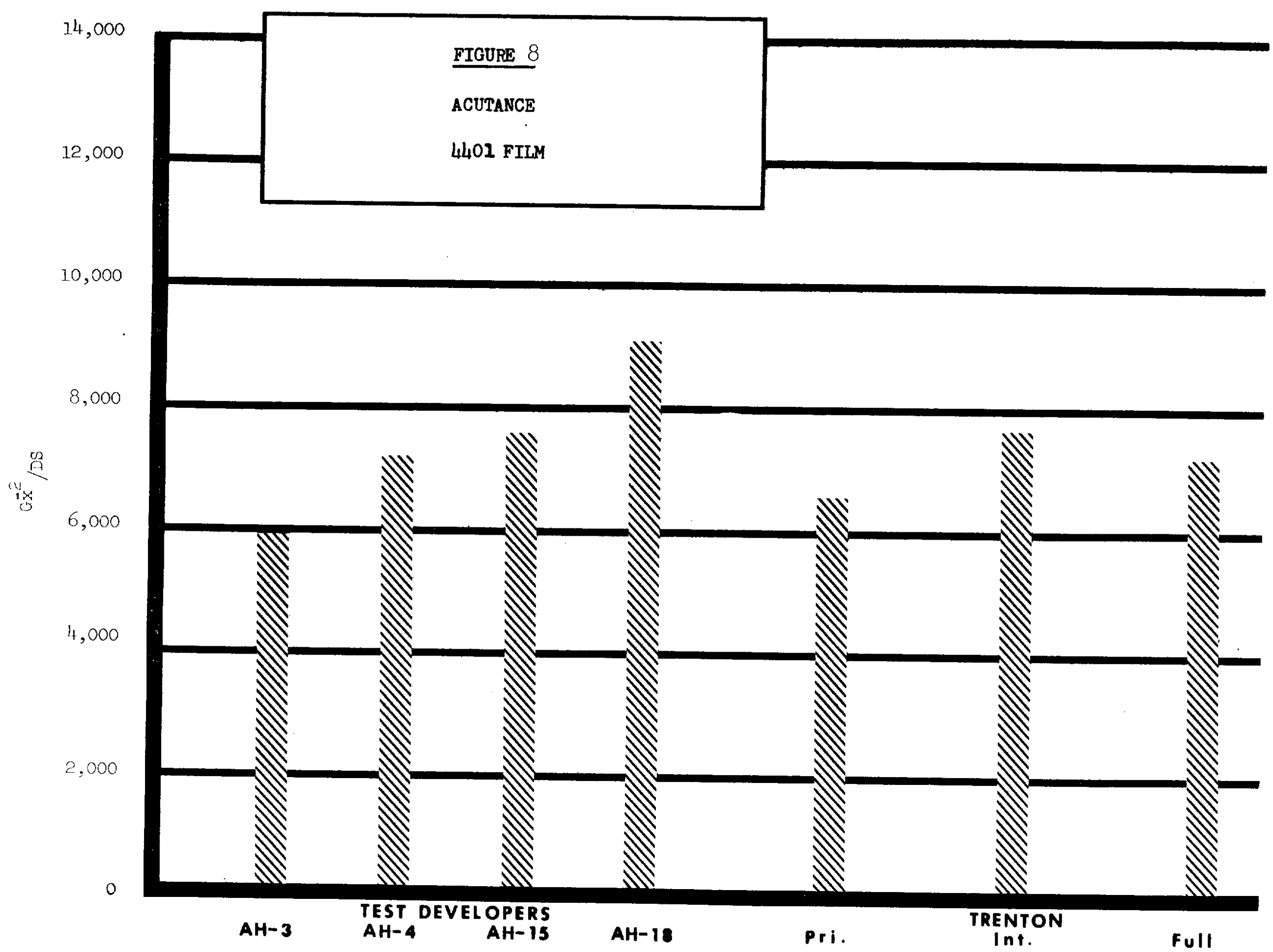

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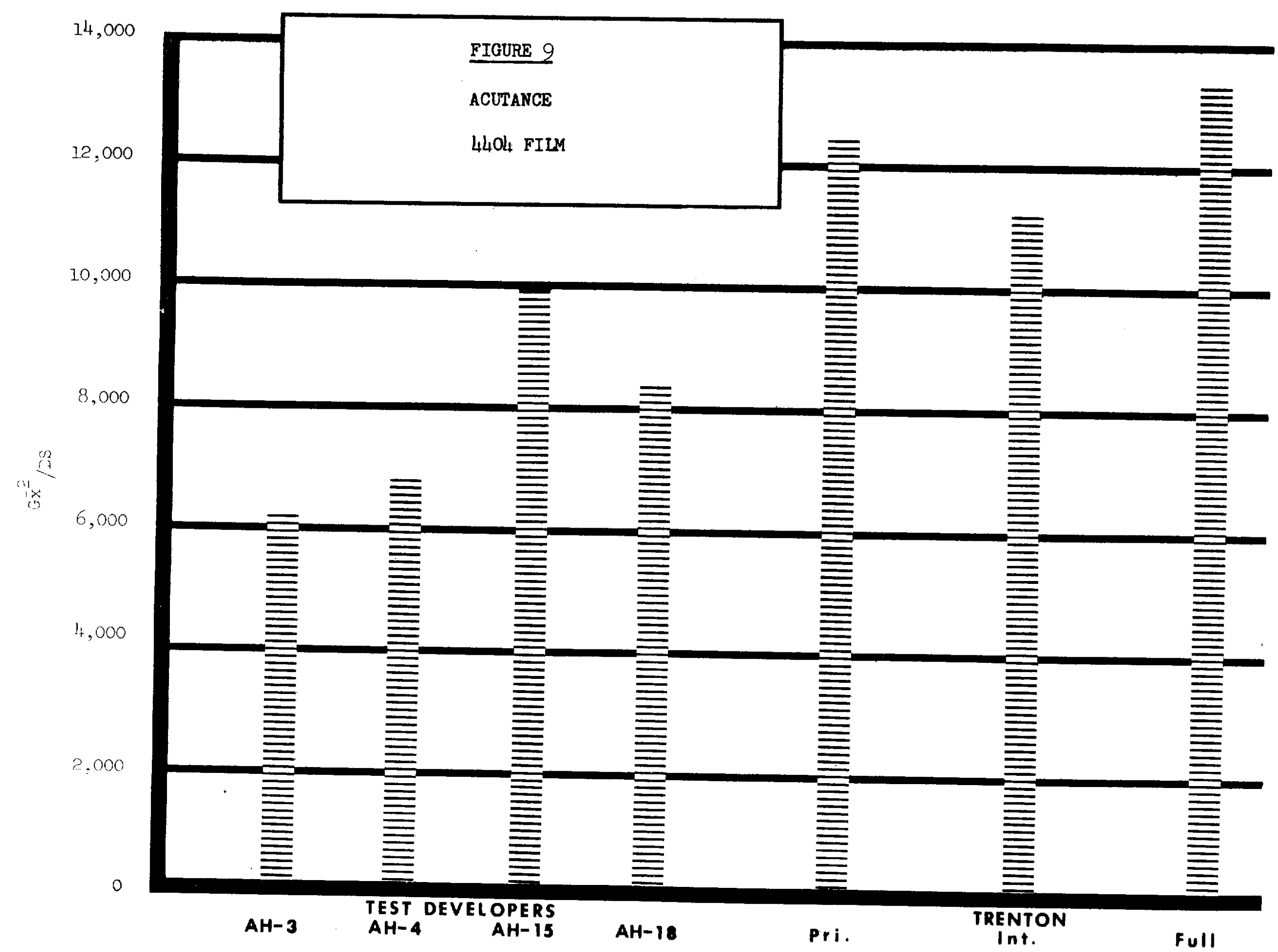
FIGURE 9

ACUTANCE

4404 FILM



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b. Granularity

(1) Photographic images appear to be homogeneous when viewed without magnification. Upon magnification, the image separates into individual grains or clumps of grains. This lack of homogeneity is the noise component of photography as a communication channel (see Reference 2), and its measure is called granularity. The granularity or graininess of an emulsion sets one of the fundamental limits to the recognition of fine detail in any photographic system. Graininess also directly influences error in linear mensuration. For these reasons, the minimization of graininess through choice of processing techniques is of interest in photoreconnaissance systems, and was included as an image structure parameter studied in this project.

(2) Altman (see Reference 3) has described the method of making granularity measurements. Briefly, this method determines the standard deviation of density about some mean density through the use of a microdensitometer. In this project, the scanning aperture was 24 microns in diameter. A curve is plotted relating the granularity values obtained at a series of exposures versus density, and the granularity is interpolated from this curve at a density of 1.0 above base plus fog.

(3) Root Mean Square Granularity values obtained are compared in Figures 10, 11, and 12.

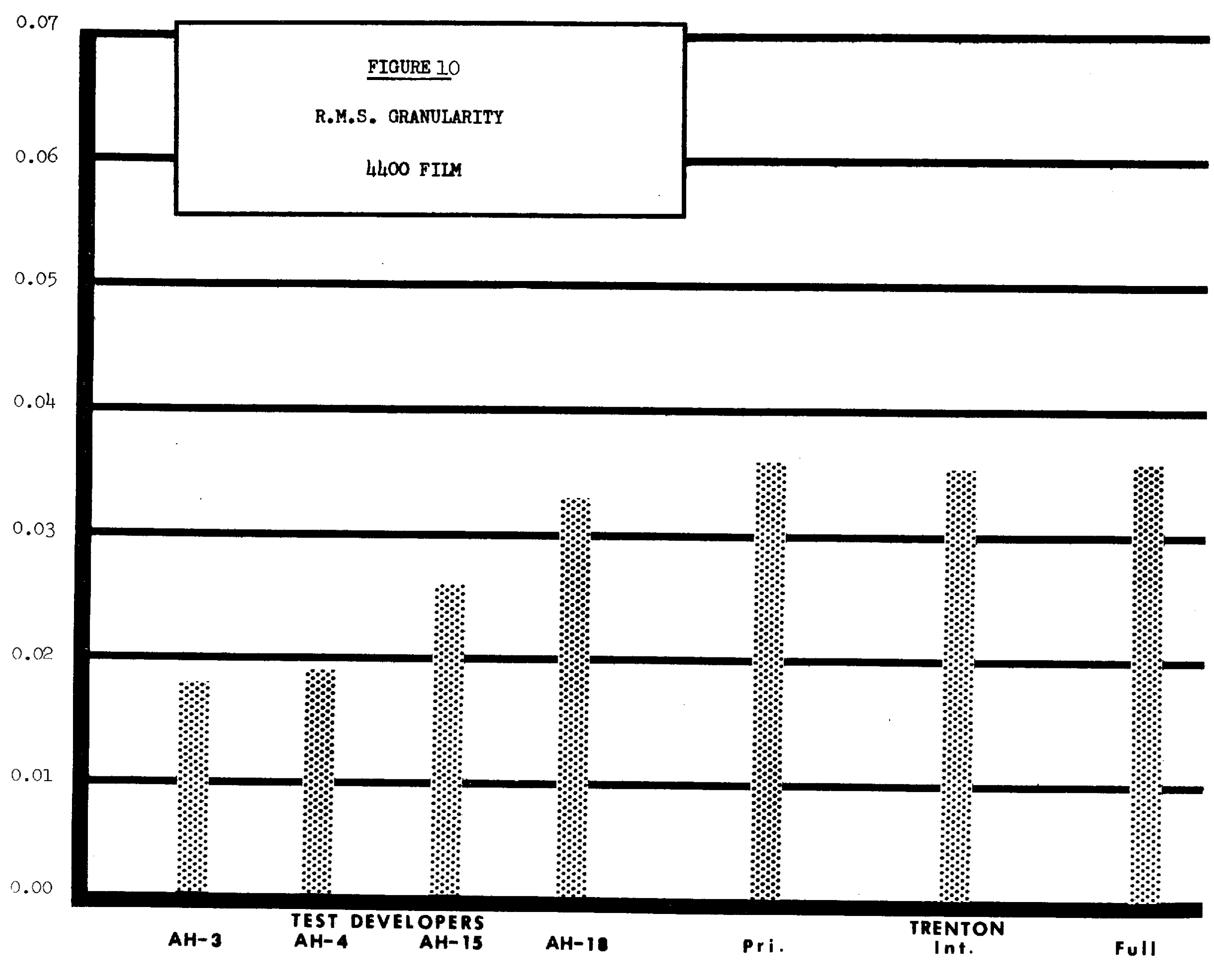

FIGURE 10

R.M.S. GRANULARITY

4400 FILM

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GROUP 1
Excluded from automatic downgrading and declassification

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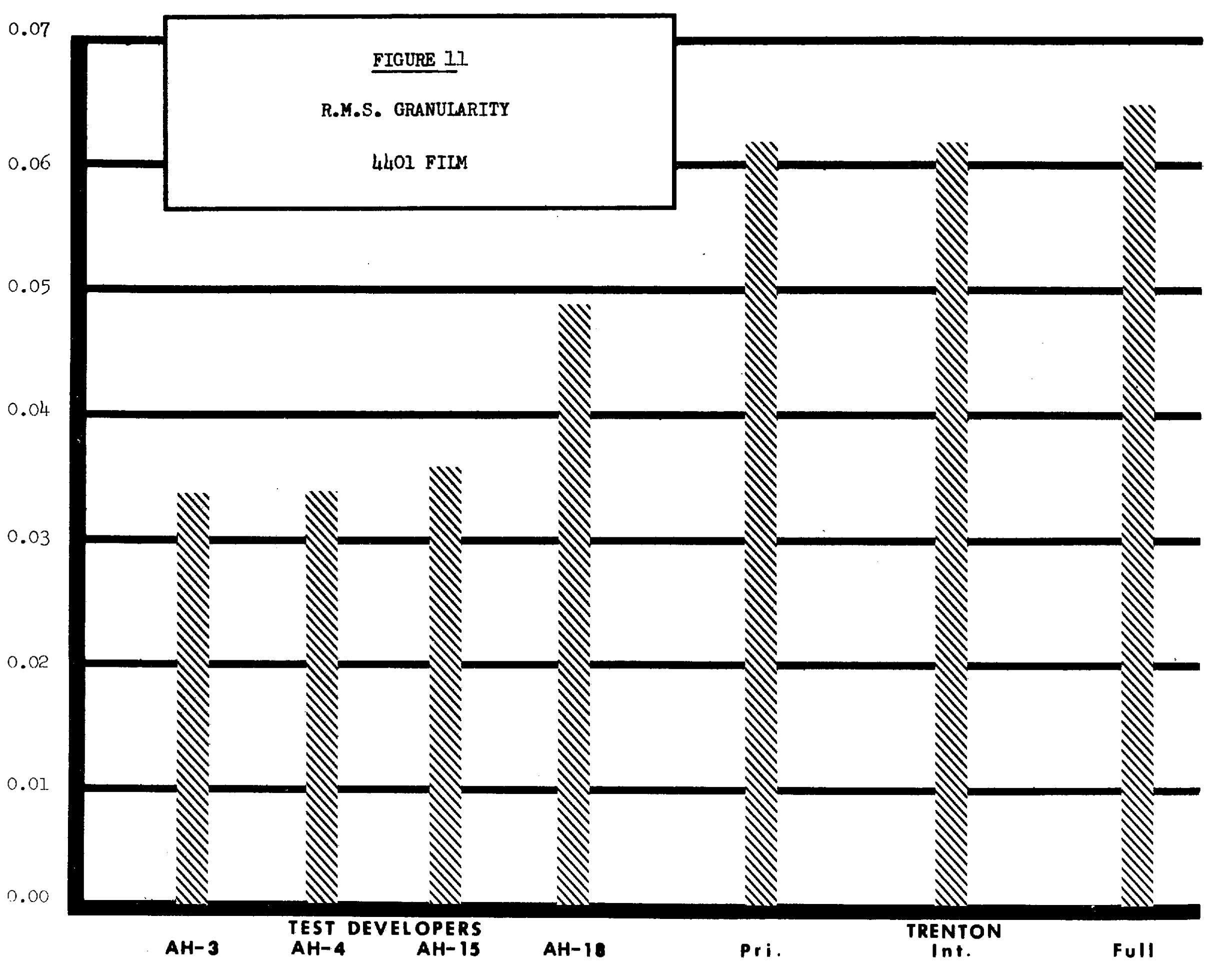

FIGURE 11

R.M.S. GRANULARITY

4401 FILM

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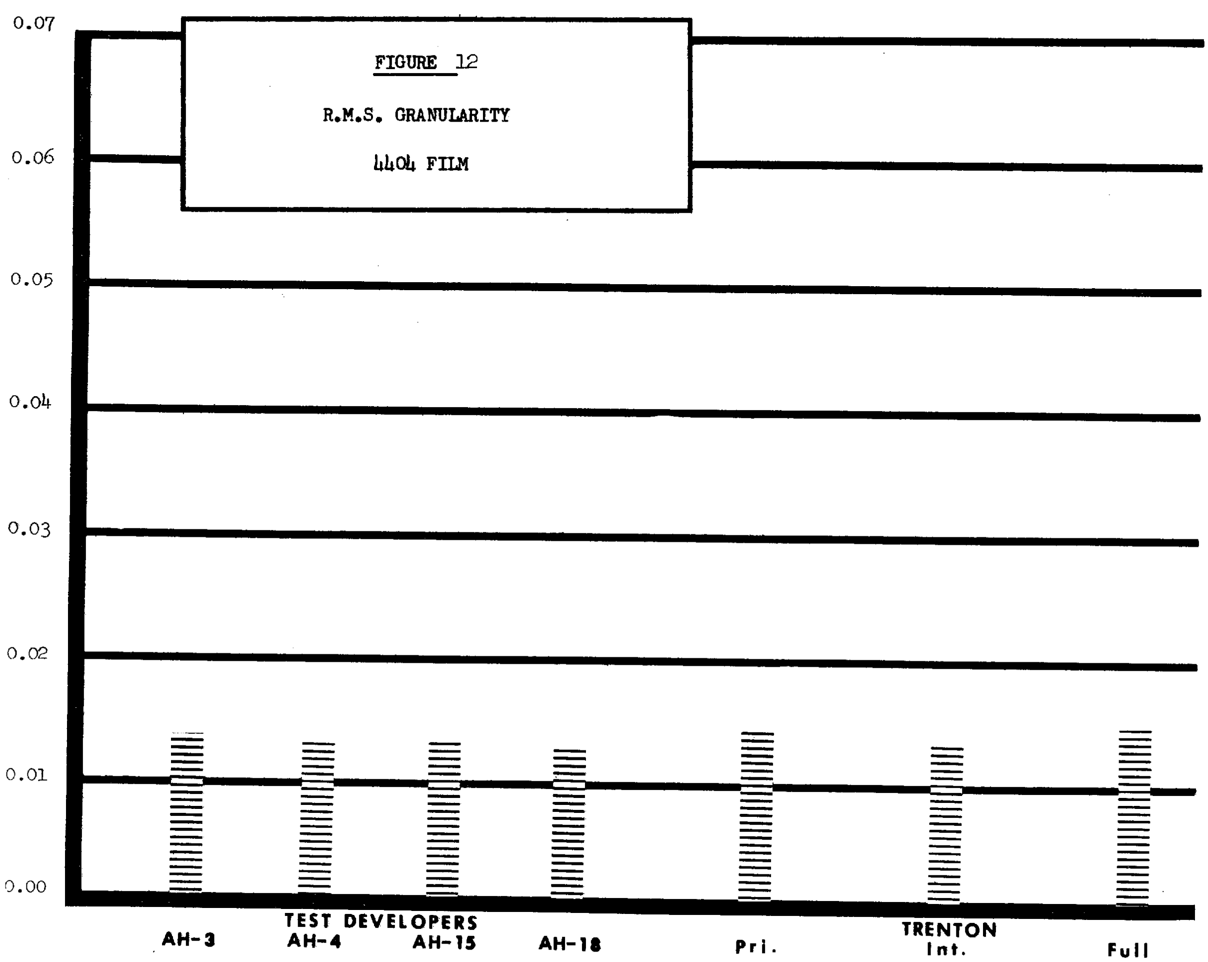

FIGURE 12

R.M.S. GRANULARITY

4404 FILM

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c. Low Contrast Resolving Power

(1) The single image structure measurement most directly correlating with the ability to recognize small details in a photographic scene is resolving power. It is also the oldest method used to characterize the image quality of a photographic system. (Reference 2.) In one measurement are combined the components of signal and noise. Such a threshold determination is by nature low in precision, and this is particularly true for resolution data at low contrast.

(2) Where possible, measurements were made in accordance with the proposed American Standard Method for Determining Resolving Power of Photographic Materials (1963). Two departures from the tentative specifications were the following:

(a) A USAF 1951 sixth-root-of-two test object was substituted for the proposed twentieth-root-of-ten chart specified.

(b) Achromatic objective lens and matching ocular lens working in restricted wavelength light (540 $m\mu$) were used in place of the proposed apochromatic objective to be used with white light.

These changes from the proposed specification were made so that the measurements would conform with the general practice at this facility during the evaluations. The contrast ratio of the exposures incident on the film under test was approximately 1.6 to 1 (log value 0.2 ± 0.02). Readout of processed film was made with a high quality binocular microscope having several levels of magnification and illumination. An exposure series was made on the film being evaluated, and the resolution value recorded for that strip was the maximum found on the strip.

(3) The resolution target camera used in this project is shown in Figure 13.

(4) Resolution test data is compared in Figures 14, 15, and 16.

d. Modulation Transfer Function

(1) The determination of the modulation transfer function is an image structure measurement characterizing only the signal portion of the signal to noise ratio in a photographic system. While the mathematics of the method and its justification as a measuring tool are somewhat involved, it may suffice to say that any test object pattern may be synthesized from sinusoidal patterns; and that if a set of sinusoidal patterns varying in wavelength is photographed on a film, the degradation of the waves can be used to compute the degradation expected of any pattern. The film/processing portion of a photographic system is one low-pass filter element of that system (see Reference 4). Lens response, image motion, etc., are additional elements of the system which may be combined by cascading to give the system response.

(2) The modulation transfer measurements made in this project were exposed on equipment described by Lamberts (see Reference 5). White light (tungsten) was used in all cases. The exposures were scanned with a Kodak Model 3 microdensitometer.

(3) Partial testing covered only the developers used in sensitometric processing. The data for these tests are illustrated in Figures 17, 18 and 19.

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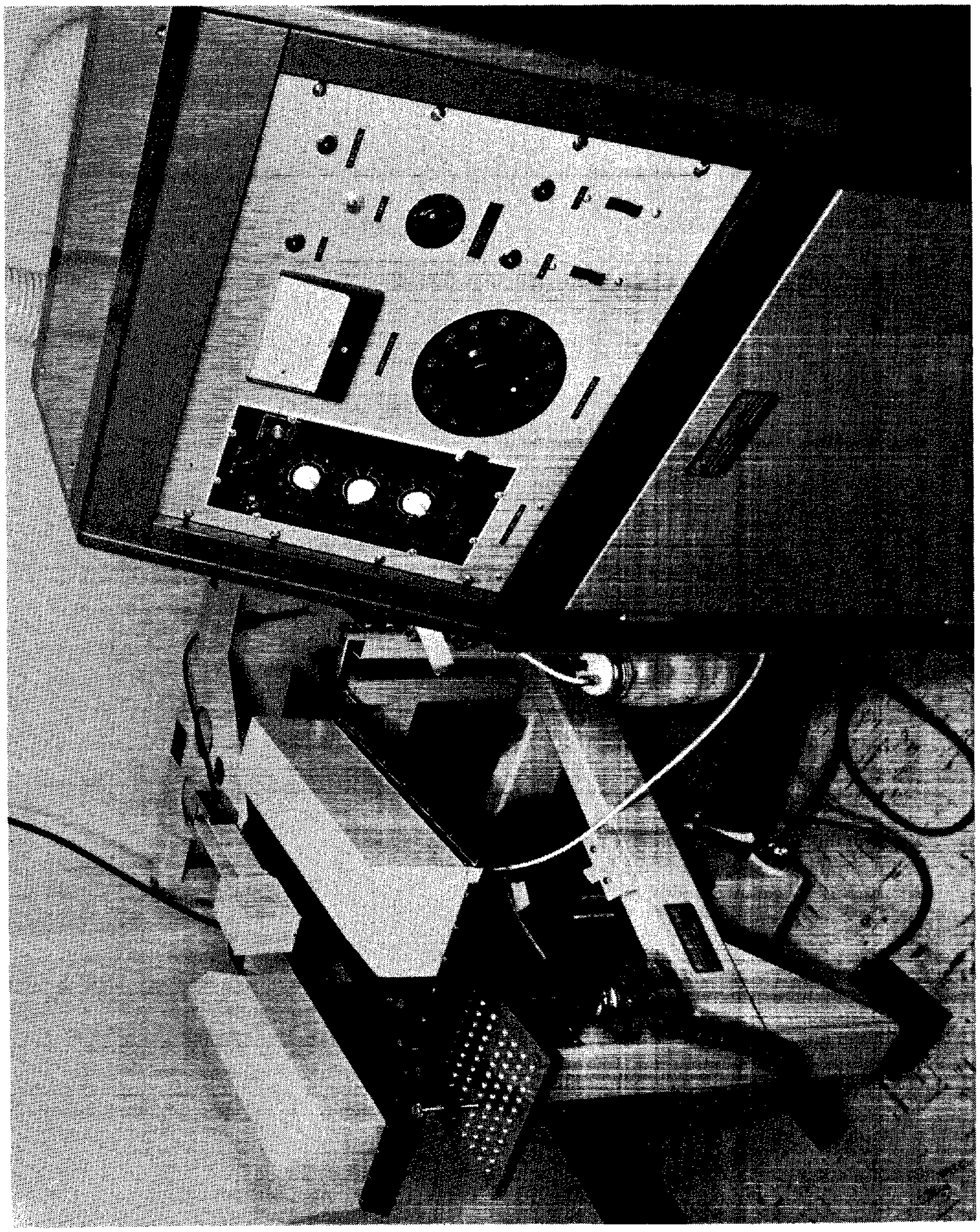

Figure 13. Resolution Target Camera and Control Console

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GROUP 1
EXCLUDED FROM AUTOMATIC DOWNGRADING AND DECLASSIFICATION

FIGURE 14

LOW CONTRAST RESOLVING POWER

4400 FILM

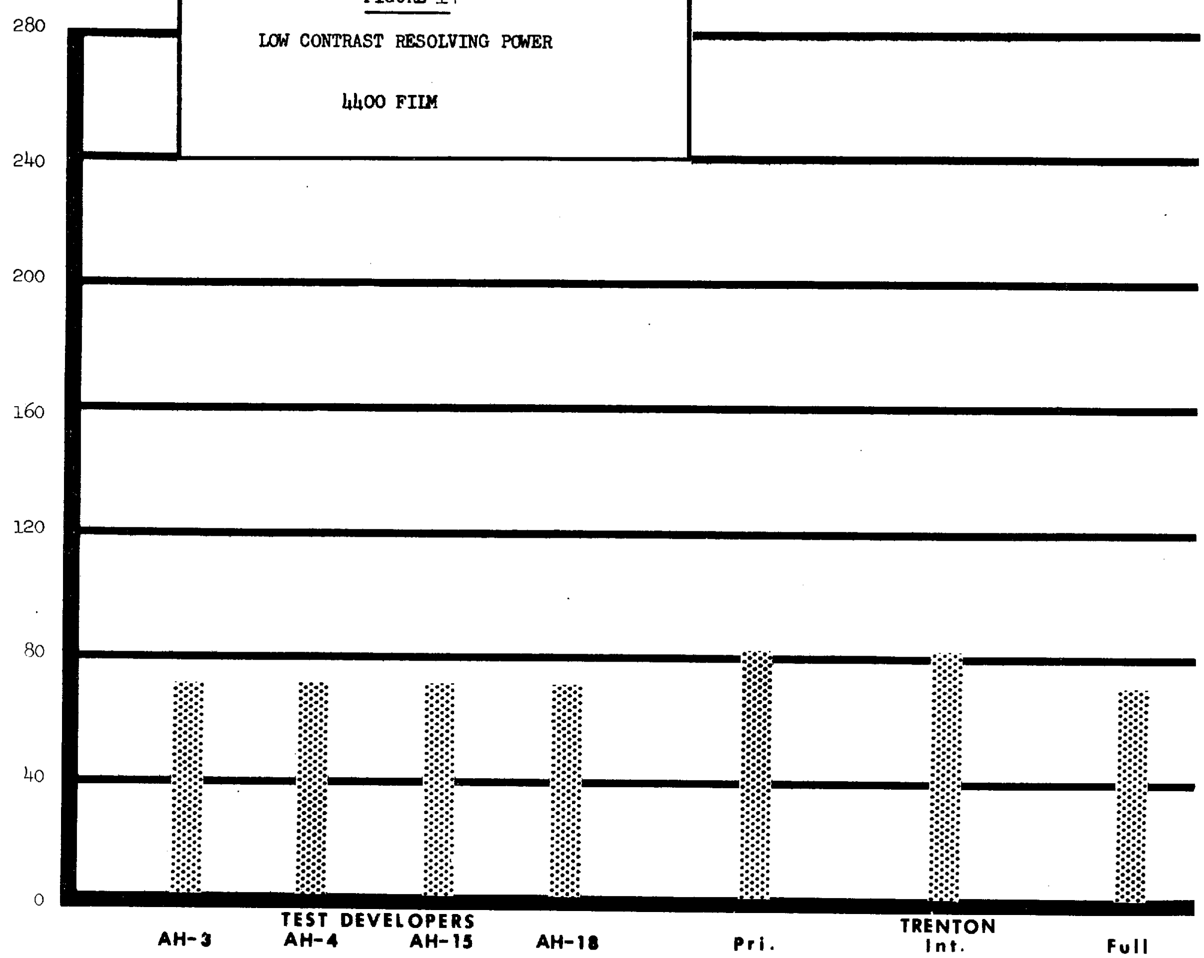

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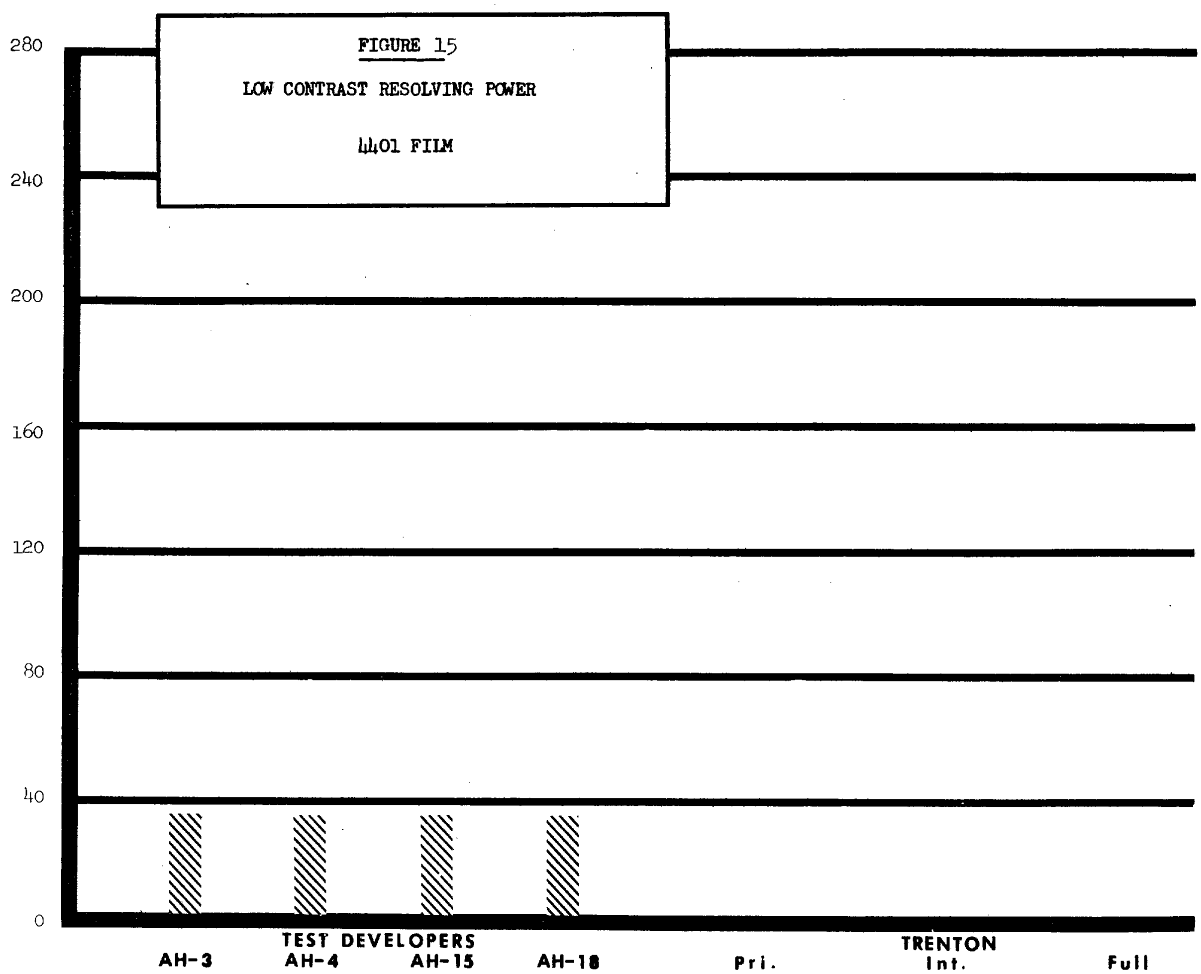
FIGURE 15

LOW CONTRAST RESOLVING POWER

4401 FILM



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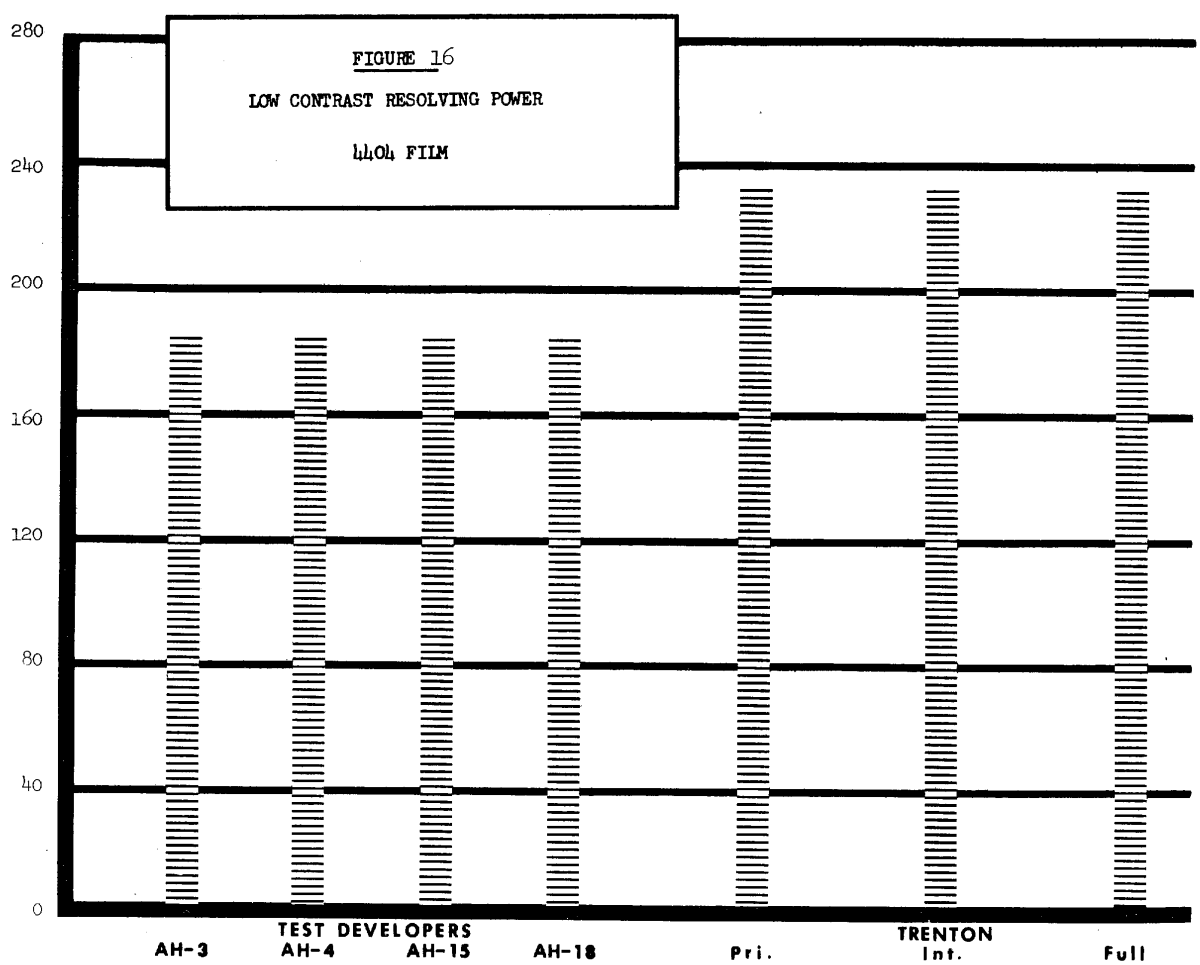

FIGURE 16

LOW CONTRAST RESOLVING POWER

4404 FILM

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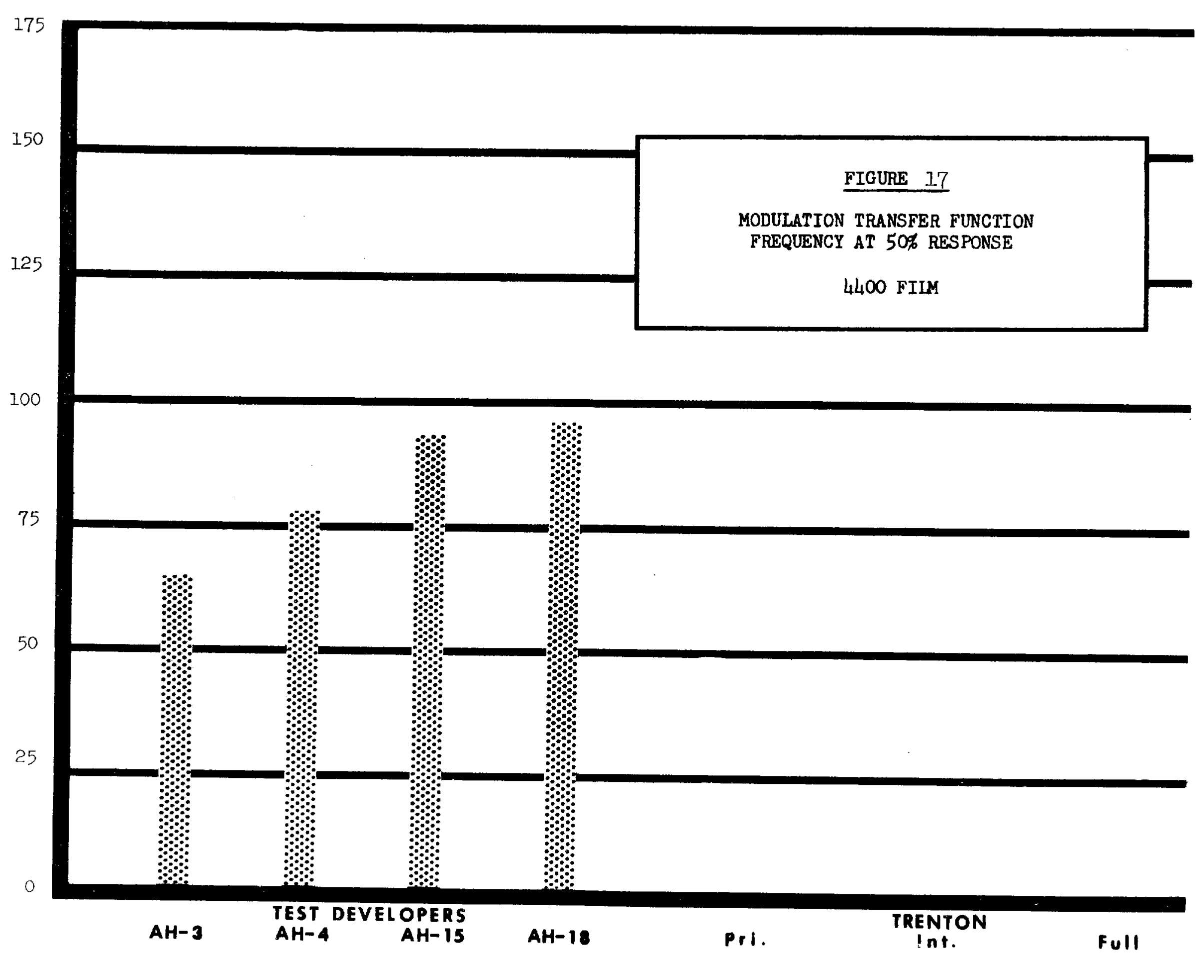

FIGURE 17

MODULATION TRANSFER FUNCTION
FREQUENCY AT 50% RESPONSE

4400 FILM

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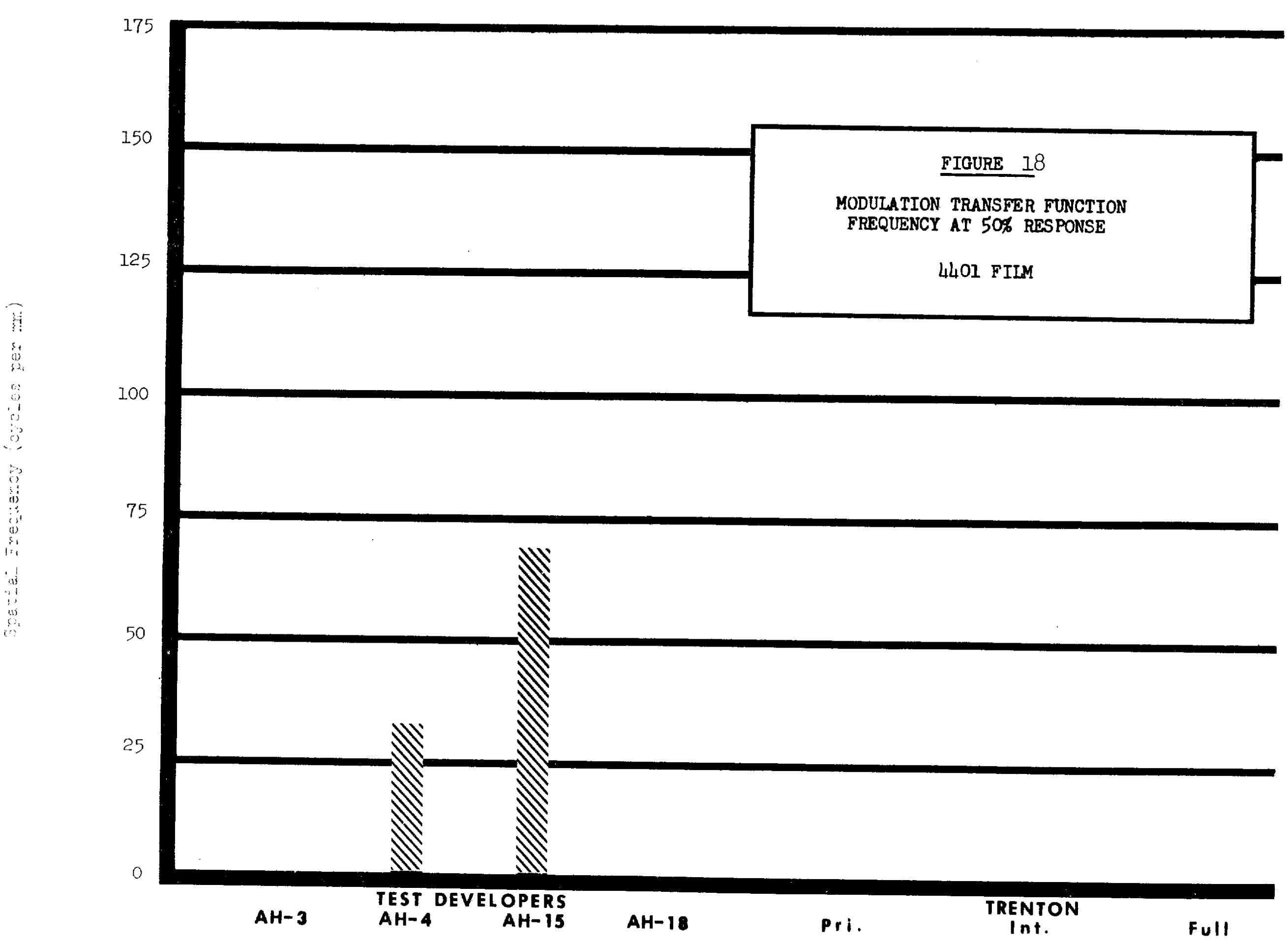

FIGURE 18

MODULATION TRANSFER FUNCTION
FREQUENCY AT 50% RESPONSE

4401 FILM

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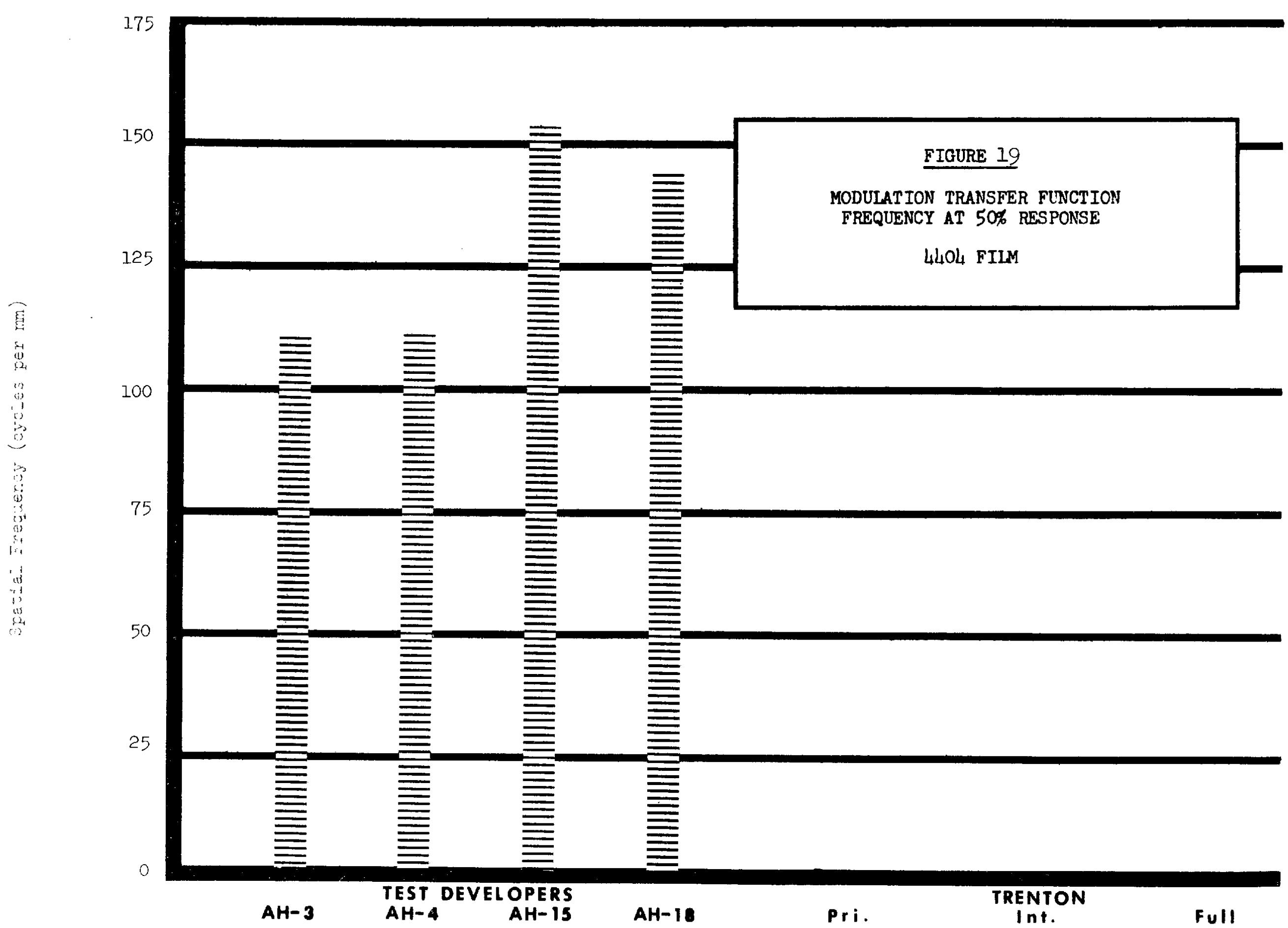

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8. Results

a. Image structure data consisting of acutance, granularity, low contrast resolving power, and modulation transfer function were collected on three aerial negative films, types 4400, 4401, and 4404 having seven processings. Standard Trenton three-condition processing was compared with four special formulations designed to give either low granularity or high sharpness. The acutance and granularity measurements for all film/processing combinations were completed, but only approximately two-thirds of the combinations of films and developers were measured for low contrast resolving power and modulation transfer function.

b. The measurements indicate that standard Trenton processing produces higher acutance, better low contrast resolving power, and poorer granularity as compared to the four special developer formulations. Because only partial results are known for modulation transfer function, no comparison of the two types of processing is possible.

c. Results are summarized by the data shown in Table 3. This table lists the values shown by histograms of Figures 7-12 and 14-19.

TABLE 3

Image Structure Results for Various Chemical Developers

	LOW CONTRAST RESOLVING POWER (LINES/MM)			ACUTANCE $G\bar{X}^2/DS$			R.M.S. GRANULARITY $\sigma(D)$			MODULATION TRANSFER FUNCTION, FREQUENCY AT 50% RESPONSE		
	FILM			FILM			FILM			FILM		
DEVELOPMENT	4400	4401	4404	4400	4401	4404	4400	4401	4404	4400	4401	4404
AH-3	73	38	185	5650	5950	6200	.018	.034	.014	65	--	111
AH-4	73	38	185	5600	7200	6800	.019	.034	.014	77	33	111
AH-15	73	38	185	8900	7600	9900	.026	.036	.014	93	69	155
AH-18	73	38	185	9100	9100	8400	.033	.049	.013	96	--	146
TRENTON PRIMARY	82	--	233	11758	6612	12464	.036	.062	.015	--	--	--
TRENTON INTERMEDIATE	82	--	233	11732	7713	11272	.036	.062	.014	--	--	--
TRENTON FULL	73	--	233	10856	7272	13388	.036	.065	.015	--	--	--

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CONCLUSIONS

9. The image structure of 4400, 4401, and 4404 film is affected by the type of developer used in processing. With composition changes, it is possible to optimize either sharpness, as measured by the parameter acutance, or graininess, measured as granularity, but it is not possible currently to combine the best sharpness and minimum graininess in a single developer formulation. Because such compromise is necessary, the choice of a developer may not be dominated by image structure criteria, but may be influenced by other characteristics such as the ability to control developed emulsion speed or tone reproduction requirements. The "informational sensitivity" of Zweig, et al (see Reference 6) or some such technique of convolving emulsion speed and image structure parameters might give a more quantitative measure of the effects of processing variations on typical aerial films.

10. Aerial simulations made at appropriate scales would have helped rank the significance of measured changes in acutance, granularity, resolution, or modulation transfer function. In absence of correlation with the subjective impression, it is difficult to assign weights to the image structure measurements for use in selection of developer formulas.

11. No significant advantage to further study is offered by introducing additional film types. Types 4400, 4401, and 4404 appear adequate as representative materials.

RECOMMENDATIONS

12. At the termination of this project, several portions were left undone. For example, the modulation transfer function and low contrast resolving power measurements were not completed, and the aerial simulations for subjective evaluation had not been started. Medium contrast resolving power was proposed but not acted upon as a supplemental phase of the project. It is recommended that these portions of the project be completed so that the influence of processing on image structure characteristics can be evaluated both objectively and subjectively.

13. A study phase of this project considered the problem of linear mensuration at or near the limit of resolution. The key to both accuracy and precision of mensuration lies in establishing the "true" location of the edge. This is the position the edge would have had in the image if any point in the object registered as an unbroadened point in the image. Two programs are recommended, aimed at aiding the determination of the "true" edge location in mission photography. Both methods require the use of the high quality measuring instruments and large scale computer available to the customer. The first method involves determination of the spread function of an edge, and the second attempts an increase in the signal-to-noise ratio in the area of the image in which the mensuration object is located.

a. Any edge in the scene becomes broadened in the photographic image. Light diffusion within the emulsion, diffraction, aberrations, and defocusing of the lens, and uncompensated image motion are some of the factors contributing to this broadening. While it is not generally possible to know the amount of each factor individually at any place in an image, the combined spreading can be estimated from either line images or from long, straight edges by microphotometer scanning and computer data transformation. It is known that line and edge tracing generally lack precision, but it may be that one or more edges traced within the frame near or perhaps including the mensuration object would yield information on the direction and amount of edge broadening. This information could then be used to establish the "true" edge location.

b. Another possible approach in dimensioning near the limit of resolution is that of the techniques involving autocorrelation, cross correlation, and optimum filtering used in communication theory (see Reference 7). Hawkins (Reference 8), Kozma and Kelly (Reference 9), and Thiry (Reference 10), have proposed techniques for increasing the signal-to-noise ratio of photographic edges through optical spatial filtering. It would seem possible to accomplish the same spatial filtering in a digital computer working from information supplied by scanning the original negative with a microphotometer. The problem is that of detection of an aperiodic signal of known shape (an edge), of unknown pulse width (object length) in the presence of noise (photographic granularity). While the purpose may be different, there seems precedence in this approach in the studies conducted on the detection of radar and sonar signals in their normally noisy environment.

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APPENDIX 1

FORTRAN PROGRAM FOR ACUTANCE CALCULATION

```
C       DATA ANALYSIS PROGRAM, S.PERRY MAY 25, 1965 NO.29-L (7044)
C       ALTERED DECK FOR BOTH DIAGNOSTIC OR PRODUCTION OUTPUT.
C       TO GET DIAGNOSTIC OUTPUT PUNCH A 1 IN COL.45 ON DATA PARAMETER
C       CARD FOR DATA ECHO AND A 1 IN COL.50 FOR OUTPUT OF ALL OTHER
C       VALUES. A 1 PUNCH IN COL.55 WILL GIVE PUNCHED OUTPUT OF SMVOLT.
        EQUIVALENCE (DSTMAG , TRVLRT)                                   DATAN011
        DIMENSION SMVOLT(401),RWVOLT(401),DATA(20),CALDEN(401)          DATAN010
        DIMENSION TITLE(4), TITL2(4), XVOLT(25), YDENS(25)
C       DEFINE MINIMUM CORCO, SAMPLING RATE, VELOCITY, LINEAR MAGNIFI-  DATAN045
C       CATION                                                          DATAN050
  204   WRITE (6,136)                                                   DATAX051
  136   FORMAT(1H , 50H*** PRO-DIAGNO PROGRAM B.B. 29-L (MAY 25,1965)**  )
  119   READ(5,13)CORMIN,DIFMAX,MXSCH                                   DATAX070
   13   FORMAT(2F10.2,I10)                                              DATAN075
        IF (MXSCH) 501,501,500
  501   MXSCH = 7
  500   IF(MXSCH.GT.100)GO TO 999
        WRITE(6,120)CORMIN,DIFMAX,MXSCH                                 DATAX076
  120   FORMAT(1H0,21HMIN. CORCO ALLOWED = ,F7.2,5X,                    DATAX077
       225HMAX. 4TH DIFF. ALLOWED = ,F7.2 /21HSLOPE SEARCH RANGE = ,I6)
  205   READ(5,10)TRVLRT,SMPLRT                                         DATAX100
   10   FORMAT(2F10.3)                                                  DATAN105
        IF (TRVLRT) 87, 87, 101                                         DATAN106
   87   WRITE(6,102)                                                    DATAX107
  102   FORMAT(1H ,16HNO TRVLRT NUMBER)                                 DATAX108
        GO TO  999                                                      DATAN109
  101   IF (100. - TRVLRT) 8, 8, 7                                      DATAN110
    8   MTEST = 1                                                       DATAN111
        WRITE(6,121)DSTMAG                                              DATAX091
  121   FORMAT(1H ,14HLINEAR MAG. = ,F12.2)                             DATAX092
C       COMPUTE INCREMENT OF X                                          DATAN895
        DELTX=2540./DSTMAG                                              DATAN093
        GO TO 88                                                        DATAN094
    7   MTEST = 2                                                       DATAN105
        WRITE(6,122)TRVLRT,SMPLRT                                       DATAX106
  122   FORMAT(1H ,17HRATE OF TRAVEL = ,F8.4,5X,                        DATAX107
       221HSAMPLES PER MINUTE = ,F8.1)                                  DATAX108
        DELTX=1000.*TRVLRT/SMPLRT                                       DATAN109
   88   WRITE(6,114)DELTX                                               DATAX110
  114   FORMAT(1H ,8HDELTX = ,F10.3)                                    DATAX111
C       READ CODE NO. AND XFOG                                          DATAN110
   11   READ(5,14)TITLE,XFOG                                            DATAX111
   14   FORMAT(4A5,F10.2)                                               DATAX112
        SDEN=0.                                                         DATAN015
        SDEN2=0.                                                        DATAN020
        SVOLT=0.                                                        DATAN025
        SVOLT2=0.                                                       DATAN030
        CNT1=0.                                                         DATAN035
        SXY=0.                                                          DATAN040
C          --- START CALIBRATION PROCEDURE                              DATAX124
        DO 15 N=1,25                                                    DATAN125
        READ(5,12)XVOLT(N), YDENS(N)
   12   FORMAT(2F4.2)                                                   DATAN135
        IF(9.99-XVOLT(N))999,16,17
   17   SDEN=SDEN+YDENS(N)
        SDEN2=SDEN2+YDENS(N)*YDENS(N)
```

```
      SVOLT=SVOLT+XVOLT(N)
      SVOLT2=SVOLT2+XVOLT(N)*XVOLT(N)
      SXY=SXY+XVOLT(N)*YDENS(N)
   15 CNT1=CNT1+1.                                                      DATAN170
C        ---  CALCULATE CORRELATION COEFFICIENT                         DATAX174
   16 CORCO=(CNT1*SXY-SDEN*SVOLT)/SQRT ((CNT1*SVOLT2-SVOLT*             DATAN175
     2SVOLT)*(CNT1*SDEN2-SDEN*SDEN))                                    DATAN180
C     CALCULATE THRESHOLD                                               DATAN185
      GO TO (41, 42), MTEST                                             DATAN190
   41 CRTSLP=12.7/DSTMAG                                                DATAN195
      GO TO 43                                                          DATAN200
   42 CRTSLP=5.*TRVLRT/SMPLRT                                           DATAN205
C     CALCULATE VOLT DATA CONVERSION COEFFICIENTS                       DATAN210
   43 SLOPE=(CNT1*SXY-SDEN*SVOLT)/(CNT1*SVOLT2-SVOLT*SVOLT)             DATAN215
      YCEPT=(SDEN*SVOLT2-SVOLT*SXY)/(CNT1*SVOLT2-SVOLT*SVOLT)           DATAN220
      IRUN=1                                                            DATAN225
      WRITE(6,100)CRTSLP                                                DATAX226
  100 FORMAT(1H ,9HCRTSLP = ,F10.5)                                     DATAX227
      WRITE(6,107)TITLE,XFOG                                            DATAX228
  107 FORMAT(1H0,4A5,F10.2)                                             DATAX229
      IF(CORCO-CORMIN)18,19,19                                          DATAN235
   18 WRITE(6,20)CORCO                                                  DATAX240
   20 FORMAT(1H ,9HCORCO OF ,F7.3,4X,7HTOO LOW)                         DATAX245
      WRITE(6,300)
  300 FORMAT(1H-,59HERRONEOUS DATA TO FOLLOW DUE TO LOW CORRELATION COEF
     2FICIENT)
      DO 308 I=1,N
  308 WRITE(6,309) XVOLT(I), YDENS(I)
  309 FORMAT(1H ,2F8.2)
      GO TO 203
   19 WRITE(6,22)CORCO                                                  DATAX255
   22 FORMAT(1H ,9HCORCO OF ,F7.3,4X,4HOKAY)                            DATAX260
C     READ DESIRED DEGREE OF SMOOTHING IN 1ST COL.  AND NUMBER OF       DATAN265
C     ITERATIONS IN 11TH COLUMN.                                        DATAN266
  203 READ(5,44)IDGSMH,NITRTN,TITL2,KDATA,KVAL,KPUNCH
   44 FORMAT (I1, 9X, I1, 9X, 4A5, 4X, I1, 4X, I1, 4X, I1)
      IF(IDGSMH)999,200,201
  200 WRITE(6,202)
  202 FORMAT(1H ,17HNO PARAMETER CARD)
      GO TO 203
  201 WRITE (6, 109) TITL2                                              DATAN276
  109 FORMAT (1H0, 4A5)                                                 DATAN277
      GO TO (119,11,205,204,206,999,206,999,206), IDGSMH                DATAN980
  206 DO 24 N=1, 400                                                    DATAN280
      SMVOLT(N)=0.                                                      DATAN285
      CALDEN(N) = 0.                                                    DATAN286
   24 RWVOLT(N)=0.                                                      DATAN290
      NOSMTH=1                                                          DATAN295
      N=1                                                               DATAN300
   28 READ(5,25)(DATA(I),I=1,20)                                        DATAX305
   25 FORMAT(20F4.2)                                                    DATAN310
      IF(KDATA)999,303,304
  304 WRITE (6, 123) (DATA (I), I = 1, 20)                              DATAX311
  123 FORMAT (1H , 20F6.2)                                              DATAX312
  303 DO 26 K=1,20                                                      DATAN315
      J=K+N-1                                                           DATAN320
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   26 CALDEN(J)=DATA(K)                                                    DATAN325
      N=N+20                                                               DATAN330
      IF(DATA(20))27,27,28                                                 DATAN335
C     BLANK VALUE IN 20TH COLUMN STOPS CARD READING                        DATAN340
   27 DO 29 MAX=1,N                                                        DATAN345
      IF (CALDEN(MAX))93, 93, 29                                           DATAN350
   29 CONTINUE                                                             DATAN351
   93 MAX = MAX - 1                                                        DATAN352
      MXNUM = MAX                                                          DATAX352
      IF (CALDEN(MAX) - CALDEN (1)) 95, 81, 94                             DATAN353
   81 WRITE(6,104)                                                         DATAX354
  104 FORMAT(1H0,43HNO DIFFERENCE IN DATA FROM ONE END TO OTHER)           DATAX355
      GO TO 99
   94 DO 96 I = 1, MAX                                                     DATAN354
   96 RWVOLT(I) = CALDEN(I)                                                DATAN355
      GO TO 30                                                             DATAN356
C        ---  INVERT DATA                                                  DATAX357
   95 DO 97 I = 1, MAX                                                     DATAN357
      J = MAX - I + 1                                                      DATAN358
   97 RWVOLT(I) = CALDEN(J)                                                DATAN359
   30 TEST = 0.5 * (RWVOLT(MAX) - RWVOLT(1)) + RWVOLT (1)                  DATAN361
        DO 55 I = 1, MAX                                                   DATAN362
      IF (RWVOLT(I) - TEST) 55, 86, 86                                     DATAN363
   55 CONTINUE                                                             DATAN364
      WRITE(6,103)                                                         DATAX365
  103 FORMAT(1H ,21HCANNOT FIND MID POINT)                                 DATAX366
      GO TO 99                                                             DATAN367
   86 IMAX = I                                                             DATAN368
  127    DO 105 I = 1, MXNUM                                               DATAN376
  105 SMVOLT(I) = RWVOLT(I)                                                DATAN377
      MAX = MXNUM                                                          DATAN359
C     START TO FORM 4TH DIFFERENCE TABLE                                   DATAN360
      K=1                                                                  DATAN365
      N = MAX                                                              DATAN371
   31 N=N-1                                                                DATAN375
      DO 32 I=1,N                                                          DATAN380
   32 SMVOLT(I)=SMVOLT(I+1)-SMVOLT(I)                                      DATAN385
      SMVOLT(N+1) = 0.0                                                    DATAN386
      IF(KVAL)999,127,305
  305 J = 1                                                                DATAX386
  126 L = J + 19                                                           DATAX387
      WRITE (6, 124) (SMVOLT (I), I = J, L)                                DATAX388
  124 FORMAT (1H , 20F6.3)                                                 DATAX389
      IF(N - J) 127, 127, 125                                              DATAX390
  125 J = J + 20                                                           DATAX391
         GO TO 126                                                         DATAX392
  127 IF(K-3)33,33,34                                                      DATAN390
   33 K=K+1                                                                DATAN395
      GO TO 31                                                             DATAN400
   34 TEST=-99.                                                            DATAN405
      DO 35 I=1,N                                                          DATAN410
      IF(ABS (SMVOLT(I))-TEST)35,35,36                                     DATAN415
   36 TEST=ABS (SMVOLT(I))                                                 DATAN420
      MAXERR=I+2                                                           DATAN425
   35 CONTINUE                                                             DATAN430
      JTEST=1                                                              DATAN435
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C     TEST TO SEE WHETHER 4TH DIFF EXCEEDS MAX VALUE                    DATAN440
      TSTMX = TEST                                                      DATAX441
      IF(TEST-DIFMAX)37,38,38                                           DATAN445
   38 WRITE(6,39)TEST,MAXERR,RWVOLT(MAXERR),IRUN                        DATAX450
   39 FORMAT(1H , 20X, 15HMAX 4TH DIFF OF , F7.3, 2X, 2HAT, I4, 4X,     DATAX455
     2   11HDATA POINT, 5X, F5.2, 5X, I4)                               DATAX460
      JTEST=2                                                           DATAN465
   37 DO 56 I=1,400                                                     DATAN615
      SMVOLT(I) = 0.0                                                   DATAN616
   56 CALDEN(I)=0.                                                      DATAN620
C     SELECT DEGREE OF SMOOTHING                                        DATAN470
      GO TO (119,11,205,204,45,999,46,999,47), IDGSMH                   DATAN980
C     START 5 POINT CUBIC SMOOTHING                                     DATAN480
   45 MAX=MAX-2                                                         DATAN485
      DO 40 I=3,MAX                                                     DATAN490
   40 SMVOLT(I)=(-3.*RWVOLT(I-2)+12.*RWVOLT(I-1)+17.*RWVOLT(I)+12.*     DATAN495
     2RWVOLT(I+1)-3.*RWVOLT(I+2))/35.                                   DATAN500
      GO TO 48                                                          DATAN505
C     START 7 POINT CUBIC SMOOTHING                                     DATAN510
   46 MAX=MAX-3                                                         DATAN515
      DO 49 I=4,MAX                                                     DATAN520
   49 SMVOLT(I)=(-2.*RWVOLT(I-3)+3.*RWVOLT(I-2)+6.*RWVOLT(I-1)+7.*      DATAN525
     2RWVOLT(I)+6.*RWVOLT(I+1)+3.*RWVOLT(I+2)-2.*RWVOLT(I+3))/21.       DATAN530
      GO TO 48                                                          DATAN535
C     START 9 POINT CUBIC SMOOTHING                                     DATAN540
   47 MAX=MAX-4                                                         DATAN545
      DO 51 I=5,MAX                                                     DATAN550
   51 SMVOLT(I)=(-21.*RWVOLT(I-4)+14.*RWVOLT(I-3)+39.*RWVOLT(I-2)+54.*  DATAN555
     2RWVOLT(I-1)+59.*RWVOLT(I)+54.*RWVOLT(I+1)+39.*RWVOLT(I+2)+14.*    DATAN560
     3RWVOLT(I+3)-21.*RWVOLT(I+4))/231.                                 DATAN565
   48 IF(KVAL+KPUNCH)999,129,306
  306 J = 1                                                             DATAX570
  131 L = J + 19                                                        DATAX571
      IF(KVAL)999,311,312
  312 WRITE (6, 128) (SMVOLT(I), I = J, L)                              DATAX572
  128 FORMAT (1H , 20F6.3)
  311 IF (KPUNCH)999,313,310
  310 WRITE(7,25)(SMVOLT(I),I=J,L)
  313 IF (MAX - J) 129, 130, 130                                        DATAX573
  130 J = J + 20                                                        DATAX574
         GO TO 131                                                      DATAX575
  129 GO TO (52,53),JTEST                                               DATAN570
   53 IF (NOSMTH - NITRTN) 54, 52, 52                                   DATAN575
   54 NOSMTH=NOSMTH+1                                                   DATAN580
      WRITE(6,60)RWVOLT(MAXERR),SMVOLT(MAXERR)                          DATAX590
   60 FORMAT ( 1H , 20X, F6.2, 2X, 7HBECOMES, F6.2)                     DATAX595
      RWVOLT(MAXERR)=SMVOLT(MAXERR)                                     DATAN585
         GO TO 137                                                      DATAN600
   52 N=IDGSMH/2+1                                                      DATAN635
C     CALCULATE DENSITY                                                 DATAN610
      DO 59 I=N,MAX                                                     DATAN625
   59 CALDEN(I)=SLOPE*SMVOLT(I)+YCEPT                                   DATAN630
      IF(KVAL)999,134,307
  307 J = N                                                             DATAX631
  135 L = J + 19                                                        DATAX632
      WRITE (6, 132) (CALDEN (I), I = J, L)                             DATAX633
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132 FORMAT (1H , 20F6.3)
    IF (MAX - J) 134, 134, 133                                  DATAX634
133 J = J + 20                                                  DATAX635
       GO TO 135                                                DATAX636
134 MAX=MAX-1                                                   DATAN655
C   COMPUTE LOWER CUTOFF                                        DATAN670
    DO 63 I = N, IMAX                                           DATAN675
    DO 64 J= 1, MXSCH, 2                                        DATAN680
    K = I + J                                                   DATAN685
    Q = J                                                       DATAN686
    IF (CALDEN(K) - CALDEN(I) - Q*CRTSLP) 63, 64, 64            DATAN687
 64 CONTINUE                                                    DATAN695
    ILOWER = I                                                  DATAN700
    GO TO 69                                                    DATAN705
 63 CONTINUE                                                    DATAN685
    WRITE(6,65)                                                 DATAX690
 65 FORMAT(1H ,15HNO LOWER CUTOFF)                              DATAX695
    GO TO 99                                                    DATAN700
 69 IF (ILOWER - N - 4) 66, 67, 67                              DATAN710
 66 WRITE(6,68)                                                 DATAX715
 68 FORMAT(1H ,29HSHOULD HAVE MORE LOWER VALUES)                DATAX720
C   COMPUTE UPPER CUTOFF                                        DATAN815
 67 DO 70 I = IMAX, MAX                                         DATAN820
    DO 71 J = 1, MXSCH, 2                                       DATAN825
    K = I + J                                                   DATAN830
    Q = J
    IF (CALDEN(K) - CALDEN(I) - Q*CRTSLP) 71, 71, 70
 71 CONTINUE                                                    DATAN840
    IUPPER = I                                                  DATAN845
    IF (MAX - IUPPER - 5) 72, 72, 84                            DATAN850
 70 CONTINUE                                                    DATAN860
    WRITE(6,80)                                                 DATAX840
 80 FORMAT(1H ,24HCANNOT FIND UPPER CUTOFF)                     DATAX845
    GO TO 99                                                    DATAN850
 72 WRITE(6,73)                                                 DATAX865
 73 FORMAT(1H ,29HSHOULD HAVE MORE UPPER POINTS)                DATAX870
C   COMPUTE GX2(AVE.)                                           DATAN920
 84 SRATIO=0.                                                   DATAN925
    DO 61 I=N,MAX                                               DATAN660
 61 CALDEN(I)=CALDEN(I+1)-CALDEN(I)                             DATAN665
    DO 89 I=ILOWER,IUPPER                                       DATAN935
 89 SRATIO=SRATIO+1000.*CALDEN(I)*1000.*CALDEN(I)/(DELTX*DELTX) DATAN940
    DMAX=SMVOLT(IUPPER)*SLOPE+YCEPT                             DATAN945
    DMIN=SMVOLT(ILOWER)*SLOPE+YCEPT                             DATAN950
    TEST = IUPPER - ILOWER                                      DATAN955
    ITEST=TEST
    ANSWER = SRATIO / (TEST* (DMAX - DMIN))                     DATAN956
    DS=DMAX-XFOG                                                DATAN960
    WRITE(6,91)IRUN,ANSWER,DS,DMAX,DMIN,IDGSMH,IUPPER,ILOWER,   DATAX965
   2  ITEST,MXNUM,TSTMX                                         DATAX966
 91 FORMAT(1H ,I3,2X,F9.1,2X,F6.2,3X,2(2X,F6.3),5(2X,I4), F8.3) DATAX970
 99 WRITE(6,98)                                                 DATAX982
 98 FORMAT(1H-)                                                 DATAX983
    IRUN=IRUN+1                                                 DATAN985
    GO TO 203                                                   DATAN986
999 CALL EXIT                                                   DATAX

    END                                                         DATAN990
```

```
*****     SAMPLE  --  TYPICAL  INPUT  DATA     *****


0.95       0.30

.0250       80.

SPITZ 15B AND 26B    .02

 145 002
 240 032
 342 080
 465 129
 637 192
 703 212
 860 268
 999

7           9

 432 433 434 435 435 434 431 430 430 429 430 431 431 431 432 430 431 431 432 434
 434 434 433 432 431 431 432 433 432 431 429 428 426 426 426 426 427 428 428 427
 428 427 427 428 430 432 434 435 436 437 438 437 437 436 434 432 433 432 433 432
 435 436 437 439 439 440 441 441 441 443 446 447 447 447 446 445 441 437 430 416
 398 371 340 310 281 252 227 205 188 176 165 158 153 151 147 145 143 142 140 139
 138 138 138 137 137 137 136 136 136 137 136 136 136 136 137 136 136 136 137 136
 137 136 136 136 136 136 136 136 136 135 136 135


*****     SAMPLE  --  OUTPUT DATA     *****
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```
*** PRO-DIAGNC PROGRAM B.B. 29-J (DEC 7,1964)***

MIN. CORCO ALLOWED =     0.95     MAX. 4TH DIFF. ALLOWED =     0.30
RATE OF TRAVEL =    0.0250     SAMPLES PER MINUTE =     80.0
DELTX =      0.312
CRTSLP =    0.00156

SPITZ 15B AND 26B          0.02
CORCC OF    0.999     OKAY

  1    30565.7    1.15      1.166   0.001     7    59    32    27   132    0.120
```

SECRET